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SOME PHASES OF THE STREAM POLLUTION PROBLEM¹

BY J. K. HOSKINS²

The increasing pollution of our streams and coastal waters has been for a considerable time a matter of serious concern to sanitarians and to those interested in the promotion of our public health, and will become a more difficult problem as our population increases, and these waters are used more intensively in the industries and as sources of public water supply. The problem is an intricate one and touches in some phase either directly or indirectly the welfare of the entire population.

There are several viewpoints from which stream pollution may be considered, more or less overlapping, yet distinct, namely, the economic, the aesthetic or recreational, and the effect on public health.

The economic side of the stream pollution problem is one that has been given little consideration until recently, but is gradually coming to be accorded the importance it deserves. Much has been said and written, demanding a return to the pristine purity of our water courses and the elimination of all pollution, regardless of the cost of such elimination. The practical absurdity of this position is becoming more and more apparent, however excellent it may seem in theory. The requirements of modern civilization demand an intensive use of our natural resources. The reasonable use of natural watercourses cannot be excluded, since they constitute one of our greatest national assets. There are, then, real, practical, economic limits beyond which it is unwise to go, in forcing abatement of stream pollution. The determination of this limit for each stream presents a problem in itself. For example, an economic study of a definite situation may disclose that it would be cheaper to procure a new source of water supply for one small municipality rather than to treat the sewage of a large up-stream city. Or it may be found more economical for an industry to change its location entirely or

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even to go out of business, rather than to incur the unreasonable expense of treating a refractory industrial waste. In general, the value of the benefits to be derived from stream purification must be weighed against the costs of elimination of pollution.

Most streams are used to a considerable extent for recreational purposes, such as for bathing, fishing, and boating, uses which are greatly retarded or even eliminated if excessive pollution is allowed to occur. The value of this use is generally intangible, and difficult to state in dollars and cents, but is, nevertheless, real. Perhaps the most common illustration of the excessive pollution of any stream is that all the fish in it have been killed. To be unable to catch fish in the brook that was formerly the ideal fishing place of our boyhood, is the superlative in condemnation of pollution in that particular stream. It must be stated, too, that the nature and variation of fish life present is a sensitive indicator of the extent of pollution in any watercourse. Boating and bathing are also affected by excessive pollution and in many cases such usage of a polluted stream becomes an important public health problem. One's esthetic sense is also revolted at the sight of grossly polluted watercourses. Floating debris, garbage, and sewage deposited along the banks, ebullition of gas from decaying sludge in stream beds, and highly discolored waters from domestic and industrial wastes afford ample grounds for complaint and demand for betterment of such conditions. While all of these factors are of secondary significance from the standpoint of health or economics, they constitute a most important phase of the stream pollution problem and the one that is, and will be, responsible for the largest share of public support in any movement for elimination of objectionable pollution.

The effect of stream pollution on public health is undoubtedly the most important phase of the problem. We must depend primarily on our streams for sources of water supply, and, in the interest of health, we must above all demand that these supplies be adequate and free from contamination. If streams are to be used for water supplies, they must either be unpolluted or methods of artificial purification of the water must be adopted to insure a suitable quality. In our present knowledge of water purification it is economically impossible to produce pure water in quantity from a grossly contaminated source. The effluent from any purification plant bears a definite relation to the condition of the raw water. It is important, therefore, that sources of water supply be not pol-

luted beyond a certain point, if the health of the community using the supply is not to be imperiled.

On the other hand, public health demands the prompt and efficient removal of body wastes, and this has been found to be best accomplished by the water carriage method of disposal. The proper method of treatment and disposal of these liquid wastes, or sewage, is therefore a public health problem closely allied to those of stream pollution and public water supply.

Because of the increasing seriousness of stream pollution, as affecting interstate watercourses, and of the demand for remedial legislation for such conditions, Congress, in 1912, authorized the Public Health Service to "investigate the diseases of man and conditions influencing the propagation and spread thereof, including sanitation and sewage, and the pollution either directly or indirectly of the navigable streams and lakes of the United States." In compliance with this authority, the Service organized and has since conducted researches to determine the fundamental factors operative in the processes of stream pollution and stream purification. The scope of the study was made sufficiently broad to cover the various types of problems to be met with, and was divided into three separate parts.

A study of the coastal waters and tidal streams was undertaken under the direction of Surgeon (now Surgeon General) Cumming. Much information was obtained on the effect of pollution on the shell fish industry and methods were developed for counteracting this pollution as it affected the production of shell fish.

Studies of the nature and treatment of industrial wastes were conducted under the supervision of Professor Earl B. Phelps. Experimental treatment plants were operated for sufficiently long periods of time to demonstrate the most effective method of handling various types of industrial wastes. At the same time much detailed data was collected pertaining to the nature and constituents of these trade wastes. The results of these studies have been published as *Bulletins of the Public Health Service*. Both of these lines of study have been discontinued, temporarily at least, because of insufficient funds to carry them further.

Studies of stream pollution and stream purification, in the inland rivers, have been organized and continued under the direction of Surgeon W. H. Frost. Intensive studies of the various phenomena

in stream purification have been carried on, with Cincinnati as a headquarters.

The greater part of the field work has been conducted on the Ohio River and its watershed. More recently the Illinois River has been under observation to determine the general applicability of the fundamental laws observed as a result of the Ohio River work.

These studies have been promoted with certain definite objects in view, although their complete attainment will require a great deal of time and the expenditure of considerable labor. These objects are briefly discussed below.

The first object is to determine the nature of the various important primary types of polluting substances in fundamental terms, and then to ascertain and evaluate the effects of these when discharged into a stream. An intelligent study of stream pollution cannot be undertaken, unless we take into account the origin and constitution of various polluting substances. This means that the actual agencies of pollution must be carefully considered and these various forms of pollution be reduced to some common standards of measurement. We must know of what domestic sewage consists, what the constituents or properties of such sewage are, and, if possible, reduce these properties to some definitely determined unit, such as the amount of oxygen required to oxidize the organic matter contained in the per capita contribution. In the same way, we should know the characteristics of the various industrial wastes, so that all of these may be reduced to fundamental and common units. For packing-house wastes, for example, we should know some unit, such as the average amount of nitrogen contributed to the waste per animal slaughtered, or the average amount of oxygen used up in oxidizing the wastes resulting from each animal handled. If some such relationships may be established, then we can say, for instance, that a contributing population of one thousand will require a definite number of pounds of dissolved oxygen in the stream to oxidize the sewage, or that 1000 animals will contribute a definite number of pounds of nitrogen to the wastes from the packing plant in which they are slaughtered, or will require a certain amount of oxygen for oxidation of these wastes. Similar fundamental units are necessary for each of the important industrial wastes that go to make up the combined pollution contributed by the community. Where there are particular wastes of importance, as, for example, the wastes from corn products industries, these should be studied in a similar way,

so that their effect on the stream may be stated in readily ascertainable units of production, such as per bushel of corn used.

Another object is to discover, if possible, the fundamental laws, if such exist, that operate in stream purification. The observed purification is a progressive process that gives evidence of following definite laws, although these may be complex and not easy of determination. There are many factors that modify the rate of purification and these may be so interwoven as to prevent separate analysis. It is certain, at least, that the old statement, that a flowing stream purifies itself in seven miles, is far from correct. We know that velocity, or time of flow, is a controlling factor, rather than distance. Temperature, both of the water and of the superimposed air, turbulence of the water, and the physical content of the water itself, exposure to light and air, all of these, and others, are factors that affect the rate of purification. Each must be studied under controlled conditions, if sound theories of purification are to be evolved.

The third object is to determine what agencies are active in the process of stream purification and the significance of the rôle of each agency in this process. It is necessary to know, for example, what particular organism or constituent is responsible for a specific, observed change in the chemical composition of the various compounds constituting pollution; what rôle such organism or constituent plays in effecting the specific change, and what the significance is of each of these factors. This is in itself a complex problem, of which little is known. We know, for instance, that in the purification process, the death rates of bacteria are a measure of the rate of purification, but we do not know what that death rate is, to what it is due, or what all of the factors are that retard or accelerate it. We believe that the plankton, both animal and vegetable forms, play an important rôle in purification processes, but we know very little about their specific activities and their food habits, or the net effect of the products they generate, such as oxygen. We know that certain classes of organisms break down into simpler forms the organic matter present as polluting substances, but just what these processes are we cannot say. We know that the process of purification depends upon the oxidation of organic matter present, but we know little of the rates at which this oxidation proceeds, or the factors that favor or retard this rate. In the process of purification certain chemical changes take place, but with our present

knowledge we have great difficulty in interpreting the meaning of these changes, modified as they are by so many other active agencies. These are some of the many problems to be solved, if we are to have an understanding of what may appear, at first thought, to be the simple problem of stream purification.

The Service plans also to make a practical study of polluted streams that are of sufficient size and representative of average conditions, to determine the net effect of various types of pollution, where these types are mixed in a practical way, and to verify the theoretical conclusions arrived at concerning stream purification. After the required data are obtained, regarding the nature and extent of the various polluting wastes, their actual effect on the watercourse into which they are discharged must be observed, and the rate at which the stream is able to recover from the pollution load must be determined. These observations should cover sufficiently long periods of time and be of broad enough scope in order that the conclusions drawn may be of general application to other places, where similar sets of conditions occur. This is the phase of the problem that is now being studied by means of the laboratories located along the Illinois River, and which will be discussed in detail later.

The results of these studies should be of practical value and general application, so that costly and tedious technical investigations need not be conducted in each individual case to determine the stream conditions to be expected from known amounts of pollution. This is perhaps the most difficult problem of all. If the solution is capable of clear statement, it should be of great value in determining for any stream what degree of purification may be anticipated at any point, due to a known amount of pollution being contributed at some point upstream. That is, if to any stream of known volume and velocity of flow, we know a population of, say 100,000, is contributing domestic sewage, it should be possible to determine within reasonable limits the amount of pollution that might be expected to be present at a point 100 miles downstream at a waterworks intake. Or, again, we should be able to estimate the effect on a surface water supply of an increase of 50,000 inhabitants on the upstream watershed, or the additional load that such an increase might be expected to contribute to a water purification plant. These conclusions should be possible without the use of extensive and costly laboratory examinations covering ex-

tended periods of time. Furthermore, such complete surveys should be of aid in establishing reasonable limits of permissible pollution and to indicate the point at which treatment of wastes must begin if objectionable conditions in the receiving stream are to be avoided.

These are some of the phases of the stream pollution problem that the Public Health Service has begun to study. Much preliminary work has been necessary to devise and to perfect methods and to collect existing data and to reduce previous independent studies to comparable terms that might be of value. To obtain the greatest benefit from the organization dealing with the study of interstate streams, the work was separated into three main divisions all of which have been carried on simultaneously with the objects in view as outlined above.

The first division has been conducting studies and experiments on the nature and effect of polluting agencies. Analyses of various classes of industrial wastes and sewage have been carried on, to establish if possible the relationship between the constituents of the waste and fundamental factors active in the production of the particular waste, regardless of the volume of the waste itself. Thus, in scouring a pound of wool, a relatively uniform amount of nitrogen is contributed to the washing waters, regardless of whether the amount of water itself is great or small. Similarly, for domestic sewage, certain constituents are more nearly proportional to the per capita population contributing than to the volume of sewage discharged. The most economical methods of treatment of such wastes have been studied at the same time.

The second division has been concerned with the phenomena of stream purification. Detailed data are being assembled dealing with the nature and extent of various kinds of pollution being contributed to certain large streams. Studies are being made of the hydraulics of these watercourses, as their velocities of flow, and amounts of water contributed by tributaries and other sources of inflow. In addition, laboratories for studying the actual degree of purification being effected at various points throughout their courses, are being operated for sufficiently long periods of time to supply reliable data.

The third division of the work has to deal with the effect of intensity of pollution on the public health, principally through the agency of the public water supply. This has involved a rather detailed study of the present methods of water treatment in various

types of plants, and the efficiencies of such plants under varying pollution loads. Studies have also been made of the actual conditions of public health in different communities, where various types of treatment plants and varying grades of water are being supplied for consumption. This work has included the making of detailed sanitary surveys of every municipality having 10,000 population, or over, on the Ohio River watershed, as well as of the greater number of cities in the eastern and North Atlantic states.

As a part of this general program, a study of conditions existing throughout the Illinois River is at present in progress. The work is not being done primarily from the viewpoint of a local problem, although some phases of it are of considerable local interest. From what has been said, it is evident that a study to fulfill the objects of the Public Health Service, as outlined above, must be made on a stream where all possible factors can be obtained in well-defined units, if results of general application are to be secured. Hence, it is advisable to choose for such study a stream where definite values are obtainable to the greatest extent. The Illinois River meets these requirements to a considerable degree.

The pollution contributed to the Illinois is largely added at one point and from a well-defined area. There is little dilution of this pollution by tributaries of the main stream, so that the observed degrees of pollution noted at various points along the channel need not be corrected appreciably because of these modifications.

The sources of pollution are known, or are readily ascertained. The population discharging sewage into the main drainage canal is clearly defined. Likewise the nature and extent of the various industries in this area have been enumerated and data are available relating to the nature and amounts of industrial wastes discharged to the drainage canal.

The volume of flow of the Illinois River is also possible of determination and the amount of water diverted from Lake Michigan is a matter of record. Surveys of the entire river channel have been made by the United States Corps of Engineers, who also maintain gages throughout the stream whereby the daily flow at any point may be computed.

Many additional pertinent data have been collected by other state and local agencies which, being available, have made the Illinois a most attractive stream for a study of the kind at present being undertaken.

In the present study of the Illinois River, the work has been separated into three main divisions. All of these are being carried along simultaneously and consist of hydrometric studies, sanitary surveys, and laboratory analyses of samples of river water.

The hydrometric studies consist in making field determinations of the daily flow of the main stream, at various points, and of all tributaries as they discharge into the main stream. This is done by making frequent current meter measurements of flow at various known gage heights. Numerous gages carefully located are read daily. From these records the daily volume of flow is computed, using the current meter measurements as a basis. A considerable amount of this work is being done in coöperation with the United States Geological Survey, which is furnishing most of the gage readers. These data are being assembled in such a way that it will be possible to state in reasonably accurate terms the total amount of water passing any sampling section on any day and the volume of water added to the main stream by each of the important tributaries of the Illinois. The amount of water being diverted daily from Lake Michigan is also known, so that the total volume of stream flow is determinable.

Another phase of the hydrometric studies has to do with the determination of the velocity of flow throughout all parts of the river. Because of the complete channel survey made by the United States Corps of Engineers, the most feasible method of determining the velocity was found to be by means of the displacement method, correlated with slope of channel as indicated by gages placed throughout the stream length. These computations are so arranged that it is possible to determine the time consumed for the water to pass from one sampling section to the next below and in that way to establish the effect that has taken place in this time interval.

Sanitary surveys have been practically completed of all important industries and municipalities contributing wastes to the stream in order to determine the extent of the contribution of pollution. Much of this information had been collected previously by various organizations, but personal visits have been made to industries and towns along the river where data were not otherwise available. It is hoped by this information to establish in fundamental terms the relationship between known populations and pollution effects observed in the stream.

The laboratory studies, concerned with the actual determination of the daily condition of the river water at numerous points throughout the course of the stream, have been the most tedious and expensive part of the work. In order to obtain reliable results the laboratory work must be carried on over a sufficiently long period of time to observe seasonal and other changes that may take place. Needless to say, the work must be thoroughly standardized and accurately performed, in order that results from all laboratories are strictly comparable in every respect.

Four laboratories have been established on the Illinois River, the main laboratory and headquarters at Peoria, and branch laboratories at Joliet, Beardstown, and Kampsville. The locations were so chosen that samples from practically every section of the river could be delivered to one of these laboratories promptly for complete examination. Definite sections were established, from which daily samples could be collected and either brought or shipped by express to the most accessible laboratory. A special type of sample collecting apparatus was devised by means of which bacteriological and chemical samples can be taken in separate bottles at the same time, and from the same water stratum. It is hoped to continue this intensive laboratory work over a complete year.

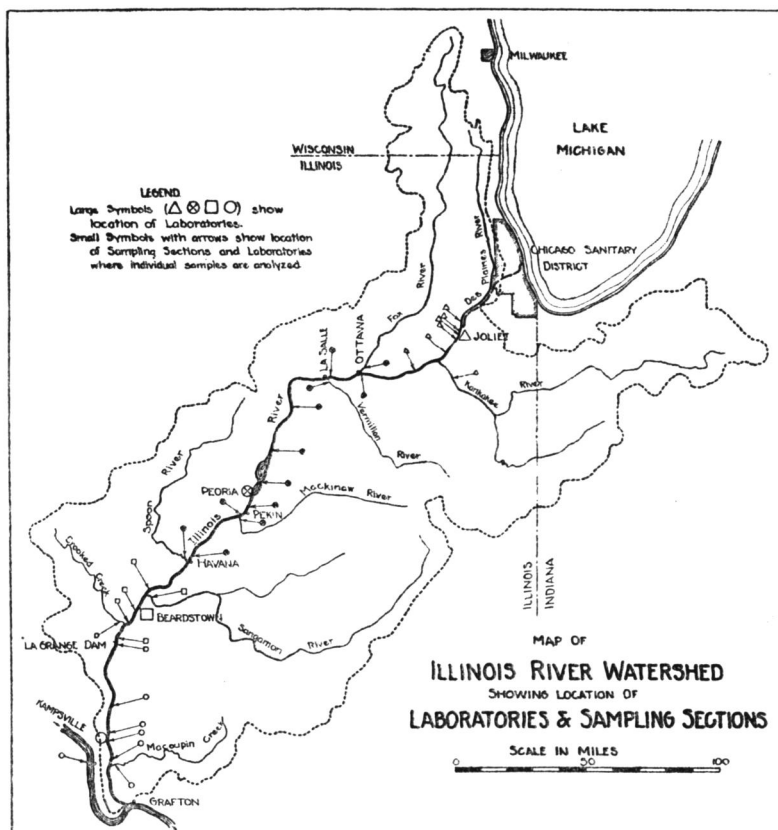
The analytical work has followed three principal lines—bacteriological, chemical and biological.

Daily bacteriological analyses are made on all samples received, in strict accordance with carefully standardized technique and by carefully trained bacteriologists. All of the culture media are made at a central point and in accordance with standard methods. The bacteriological determinations consist of numbers of bacteria growing on gelatin at 20°C. in 48 hours, and on agar at 37° in 24 hours, and the numbers of *B. coli* computed by the decimal dilution method. Differentiation of types of *B. coli*, grain or fecal, by means of dextrose peptone phosphate broth, is made on a certain percentage of all *coli* cultures isolated.

The chemical work has been considerably reduced because, from past experience, it has been found that many complete mineral analyses are not justified. The alkalinity and turbidity are determined for all samples collected, as well as the immediate dissolved oxygen. The biochemical oxygen demand is also determined for every sample, using the dilution method and incubating the sample for a period of 5 days at a temperature of 20°C., and ascertaining

the dissolved oxygen present at the end of this incubation period. We believe this to be one of the most valuable tests at present in use for indicating the degree of pollution and the rate of purification that may be expected to occur from such pollution.

Composite samples, covering periods of ten days, are made, preserved with sulphuric acid, and analyzed for certain constituents



such as oxygen consumed, free ammonia, Kjeldahl nitrogen, and nitrogen oxides, including nitrates and nitrites. It has been found by a careful series of experiments that the sulphuric acid preserves such samples without change for a sufficiently long period of time to make this method entirely practicable.

The biological part of the laboratory studies has been designed more or less to supplement the extensive work of the State Natural

History Survey, and to correlate the present findings with the observations so carefully made by Professor Forbes and his workers. Consequently, only a small part of the biological field is being touched. Monthly samples of bottom sediment are collected at selected points and the nature and amount of the contents of these various sludge deposits are noted. Weekly samples of plankton are collected from many more sampling stations, and these plankton forms are counted, identified, and recorded. Special attention is paid to the presence of those forms which, in their processes of development, generate and impart oxygen to the surrounding water, and thus influence the rate of oxidation of the organic matter present.

The accompanying map of the Illinois watershed shows the location of the laboratories, indicated by large symbols, while the arrows with the small symbols indicate the points at which daily samples of water are collected for analysis. Sampling sections indicated by a certain symbol, as a triangle, indicate that samples from this point are analysed in the laboratory designated by a similar symbol.

The data being collected have not yet been arranged in final form, so that it is not practicable at this time to draw definite conclusions as to the rates of purification to be expected, although the results seem to follow the same general trend of those obtained in the Ohio River work.